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USE OF VARIABLE-RATIO GEARED TABS TO IMPROVE STICK-FORCE CHARACTERISTICS IN TURNING FLIGHT

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USE OF VARIABLE-RATIO GEARED TABS TO IMPROVE STICK-FORCE CHARACTERISTICS IN TURNING FLIGHT

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SUMMARY

In flight tests of an experimental elevator with geared tabs, a cockpit control over the tab gear ratio was found to be satisfactory for adjusting the stick force per g in turning flight according to the pilot's preference. This type of control appears to have application for increasing the center-of-gravity range for satisfactory stick forces in turning flight. Sample calculations made for a fighter airplane indicate that satisfactory stick forces in turning flight can be obtained for any center-of-gravity position at which the elevator control meets other requirements.

INTRODUCTION

Because of the increase in weight and in altitude range, most recent airplanes meet Army and Navy specifications for satisfactory stick forces in turning flight for only a limited center-of-gravity range. Attempts have been made to provide satisfactory stick forces for an increased center-of-gravity range by the use of spring-tab elevators and by a reduction in the variation of elevator hinge moment with elevator deflection C_{h_δ}. If any appreciable increase in center-of-gravity range is obtained by either of these methods, it is then necessary to add a bobweight or to make the variation of elevator hinge moment with tail angle of attack C_{h_α} positive in order to increase light stick forces in turns at normal center-of-gravity positions. Arrangements of this kind have introduced undesirable control feel in rapid maneuvers and poor control characteristics in rough air. With spring tabs, in addition, difficulty in preventing

flutter and in maintaining the stick force per g sufficiently constant throughout the speed range may be encountered.

A method is suggested for increasing the center-of-gravity range for satisfactory stick forces in turning flight by the use of geared tabs and a cockpit control over the gear ratio. Flight tests have been made with an arrangement of this kind, and pilots' opinions of such a control are now available.

SYMBOLS

b_e elevator span, feet

$\bar{c}$ wing mean aerodynamic chord, feet

$\bar{c}_e$ elevator root-mean-square chord, feet

C_{h_δ} variation of elevator hinge moment with elevator deflection $\left(\frac{\partial C_h}{\partial \delta_e}\right)$

C_{h_α} variation of elevator hinge moment with tail angle of attack $\left(\frac{\partial C_h}{\partial \alpha_T}\right)$

C_h elevator hinge-moment coefficient $\left(\frac{H}{q b_e \bar{c}_e^{\,2}}\right)$

H hinge moment, foot-pounds

q dynamic pressure, pounds per square foot

C_{L_T} tail lift coefficient

$\left(C_{L_\alpha}\right)_T$ tail lift-curve slope, per radian $\left(\frac{\partial C_{L_T}}{\partial \alpha_T}\right)$

K ratio of stick movement to elevator deflection, feet per radian

l_T tail length, distance from center-of-gravity position to elevator hinge line, feet

S_T horizontal-tail area (exclusive of area through fuselage), square feet

W airplane weight, pounds

α_T tail angle of attack, radians

δ_e elevator deflection (positive down), degrees

δ_t tab deflection (positive down), degrees

δ_t/δ_e tab gear ratio

τ elevator effectiveness factor $\left(\dfrac{\partial C_{L_T}/\partial \delta_e}{\partial C_{L_T}/\partial \alpha_T}\right)$

FLIGHT TESTS

A cockpit control over the tab gear ratio was used during flight tests of an experimental all-movable horizontal tail on a fighter airplane. With the all-movable tail the tabs were used as geared unbalancing tabs, and ratios of tab deflection to elevator deflection δ_t/δ_e of 0.6 to 1.0 were available. At the center-of-gravity location tested, the corresponding stick force per g in turning flight varied approximately from 6 to 10 pounds at an altitude of 5000 feet.

The control was found to be satisfactory for adjusting the stick force per g to the pilot's preference. The pilots preferred a force of about 8 pounds per g in the present flights, which did not involve high accelerations. The pilots reacted favorably to the control and did not think it confusing in any way. It is believed that, after elementary education in the function of the control, pilots would use it as instinctively as they use the trimming controls.

TYPICAL APPLICATION AND DISCUSSION

In the flight tests of the all-movable tail with variable-ratio geared tabs, the control characteristics could not be determined over a large center-of-gravity range. In order to illustrate the increased range for which satisfactory stick forces in turns can be obtained, therefore, calculations have been made for a typical fighter airplane with conventional elevators. The characteristics of this airplane are given in table I. The variation of stick force per g with center-of-gravity position was calculated from the equation

$$\frac{\text{Stick force per g}}{\text{Percent change in c. g. position}} = 0.01C_{h_\delta}\frac{W\bar{c}b_e\bar{c}_e^{\,2}}{K\tau\left(C_{L_\alpha}\right)_T S_T l_T}$$

In this equation the hinge moments of the tab are neglected.

Calculations were made for two sets of values of the elevator hinge-moment coefficients C_{h_α} and C_{h_δ}. For the first example it was assumed that $C_{h_\alpha} = 0$ and $C_{h_\delta} = -0.002$. The value of $C_{h_\alpha} = 0$ may be obtained in practice by a suitable choice of the elevator contours. For the second example it was assumed that $C_{h_\alpha} = -0.001$ and $C_{h_\delta} = -0.0035$; these values are typical of those obtained on elevators of several current fighter airplanes. For both examples the elevator hinge-moment coefficient due to tab deflection was assumed to be -0.0035; values close to -0.0035 have been obtained in practice with tabs the same size as those of the airplane considered for the calculations.

The curves showing the variation of stick force per g with center-of-gravity position for the two examples are presented in figure 1. The range of satisfactory stick forces is indicated in figure 1 in accordance with the requirements of reference 1. The locations of the stick-fixed neutral point and the stick-fixed maneuver points were estimated from flight-test data on an airplane of this type. The stick-fixed neutral point is the center-of-gravity position at which the variation of elevator angle with airplane lift coefficient is zero in

straight flight. The stick-fixed maneuver point is the center-of-gravity position at which the variation of elevator angle with airplane lift coefficient is zero in turning flight.

Figure 1 shows that a greatly increased center-of-gravity range for satisfactory stick forces in turning flight is possible with a variable-ratio geared tab control. In addition the control permits the pilot to adjust the force to his own preference at any intermediate center-of-gravity position. The center-of-gravity range can be extended forward any arbitrary amount if sufficient tab power and elevator balance are provided. The most forward center-of-gravity position then will be determined not by limits on stick forces in turning flight but by other considerations, such as the elevator deflection available to meet landing requirements. Figure 1 also shows that the most rearward center-of-gravity position for which the variable-ratio tab control can be used to obtain satisfactory stick forces in turning flight is somewhat forward of the stick-fixed maneuver point. This limit will be at least as far rearward as the limit set by the stick-free or stick-fixed neutral points. With a control over the gear ratio of geared elevator tabs, therefore, satisfactory stick forces in turning flight could be provided for any center-of-gravity position at which the elevator control would meet other requirements.

When Ch_{α} is negative, a condition of stick-free instability in turns would be obtained if the control over the tab gear ratio were used in the position to give light stick forces at a rearward center-of-gravity position; for example, if a tab gear ratio of -0.5 (fig. 1(b)) were used at 32 percent mean aerodynamic chord. This condition would be dangerous in take-off and, although an item could be included in the check-off list for take-off to have the control in position to give heavy stick forces, the possibility of this condition should be avoided by the use of an elevator with $Ch_{\alpha} = 0$.

A second advantage is gained if an elevator with $Ch_{\alpha} = 0$ is used. When Ch_{α} is negative, larger negative values of Ch_{δ} are required to obtain sufficiently heavy stick forces at rearward center-of-gravity positions and larger tab gear ratios or larger tabs are required to provide a given increase in center-of-gravity range. (Compare figs. 1(a) and (b).)

It has recently been found that zero is the approximate limit to which Ch_α can be changed in the positive direction when Ch_δ is small unless some auxiliary device is used to eliminate the undesirable control feel in rapid maneuvers. Elevators with $Ch_\alpha = 0$ have been found satisfactory when Ch_δ was sufficient to give 5 to 8 pounds per g. An elevator with $Ch_\alpha = 0$ and with Ch_δ large enough to give only 2 or 3 pounds per g would probably give uncomfortably light stick forces.

When the tab ratio is changed, the stick-free stability in straight flight (variation of stick force with airspeed) will change as well as the stick force per g in turning flight. If the variable-ratio tab control is used to maintain an essentially constant value of stick force per g through the center-of-gravity range, more nearly constant stick-free stability in straight flight through the center-of-gravity range will result than is obtained with conventional elevators.

In addition to improving stick-force characteristics in turning flight, a variable-ratio geared tab control may be useful in compensating for variations in Ch_α and Ch_δ due to manufacturing tolerances and other factors that prevent accurate prediction of hinge-moment characteristics.

DESIGN CONSIDERATIONS

Tab power greater than is normally provided for trimming may be necessary if the elevator tabs are employed both as geared tabs and as trim tabs. If a reasonable amount of elevator balance is provided, however, the necessary tab gear ratios will be small and the added demand for tab power will not be difficult to meet. The required tab ratios may be reduced by providing sufficient elevator balance to allow the tabs to be used as unbalancing tabs for rearward center-of-gravity positions and as balancing tabs for forward center-of-gravity positions. Tab power additional to that normally provided may also be necessary to trim the stick force in the landing

approach if the center-of-gravity range is extended forward. The amount of additional tab power for this purpose will of course depend on the amount of elevator unbalance and the size of the tabs, but estimates from flight-test data indicate that a tab deflection of approximately 1° per percent center-of-gravity movement would be needed for the elevators assumed in the first example.

In order to avoid large deviations from linearity in the curves of elevator hinge moment with elevator deflection at large elevator deflections, the maximum tab deflections should be limited to reasonable values, probably not greater than 20°. A small-chord tab of large span is, in general, preferable to a large-chord tab of small span.

The job of providing a cockpit control over the tab gear ratio is structurally and mechanically similar to that of providing trim-tab control. A diagrammatic sketch of an installation that would provide variable tab gear ratios and tab movement for trimming is shown as figure 2. Definite stops should be provided to limit the adjustment of the tab gear ratio to the amount needed to give satisfactory stick forces over the center-of-gravity range that is to be used. If stops are not provided, a condition of zero or positive C_{h_δ} might be obtained. This condition, of course, must be avoided.

CONCLUDING REMARKS

In flight tests a cockpit control over the gear ratio of a geared elevator tab was found to be satisfactory for adjusting the stick force per g in turning flight according to the pilot's preference. This type of control appears to have application for increasing the center-of-gravity range for satisfactory stick forces in turning flight. Sample calculations made for a fighter airplane indicate that satisfactory stick forces in turning flight can be obtained for any center-of-gravity position at which the elevator control meets other requirements.

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REFERENCE

1. Anon.: Stability and Control Characteristics of Airplanes. AAF Specification No. R-1815-A, April 7, 1945.

TABLE I

AIRPLANE CHARACTERISTICS USED IN CALCULATIONS

Airplane weight, pounds	11,000
Wing area, square feet	334
Wing span, feet	42.8
Wing mean aerodynamic chord, feet	8.12
Tail length, feet	21.4
Horizontal-tail area, square feet	69.5
Elevator area, square feet	25.8
Elevator span, feet	18.5
Elevator root-mean-square chord, feet	1.46
Tab span, feet	4.85
Tab chord, foot	0.42
Tail lift-curve slope, $\left(C_{L_\alpha}\right)_T$, per radian	3.7
Elevator effectiveness factor, τ	0.5
Elevator deflection, degrees	±25
Ratio of stick movement to elevator deflection, feet per radian	1.72

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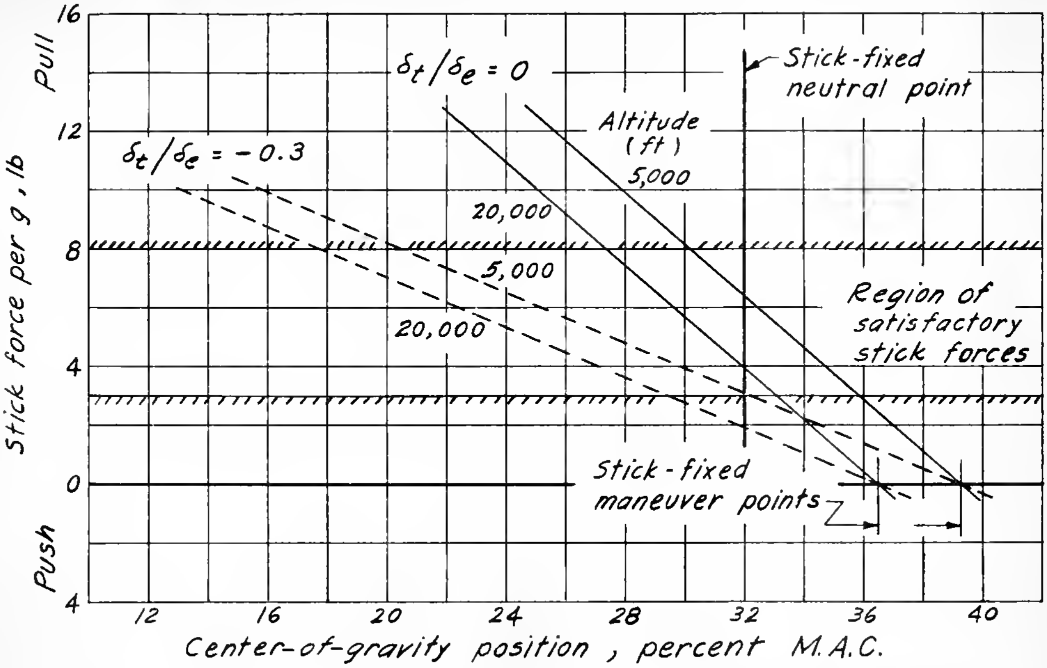
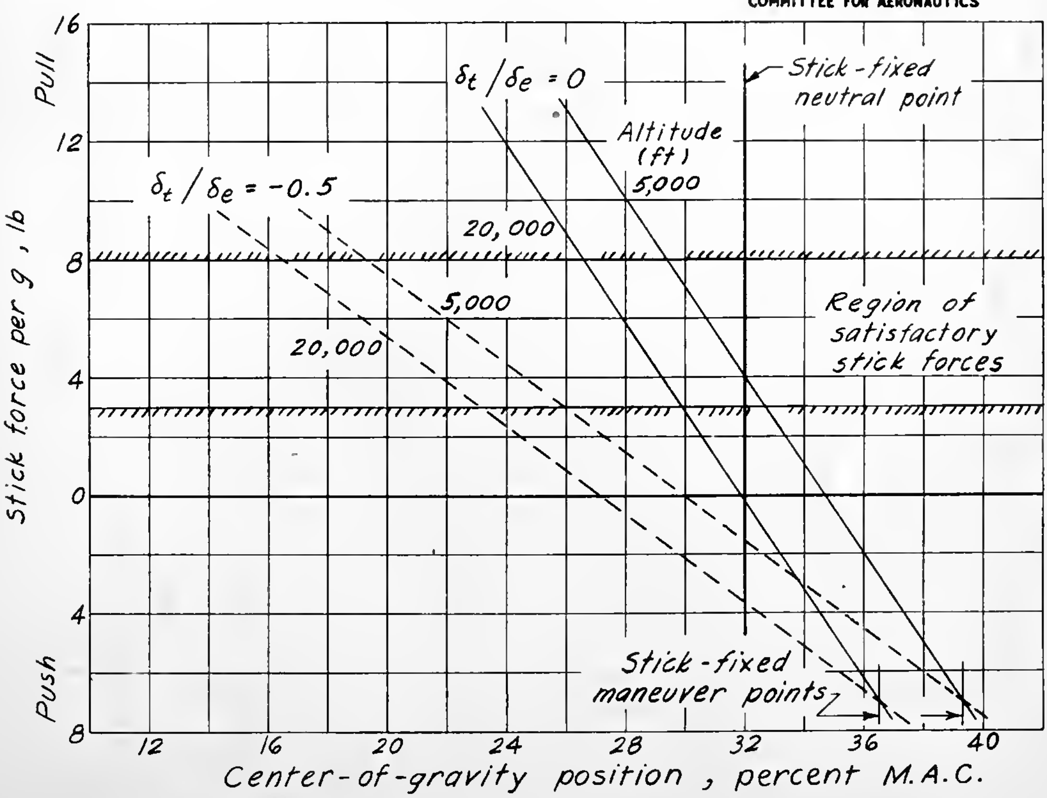


(a) $C_{h_\alpha} = 0$; $C_{h_\delta} = -0.002$.



(b) $C_{h_\alpha} = -0.001$; $C_{h_\delta} = -0.0035$.

Figure 1. - Variation of stick force per g wit' enter-of-gravity position for a typical fighter ai: ne.

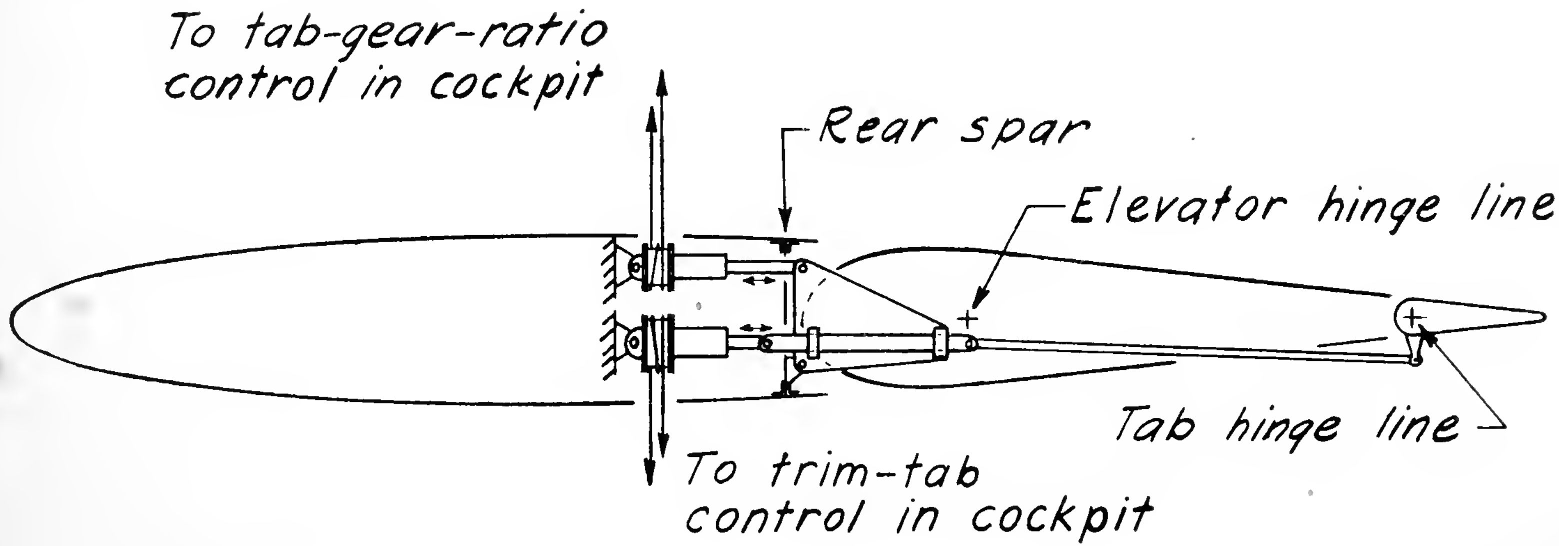


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Figure 2. - Tab controls to provide variable tab gear ratios and tab movement for trimming.